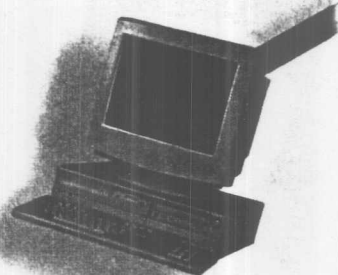
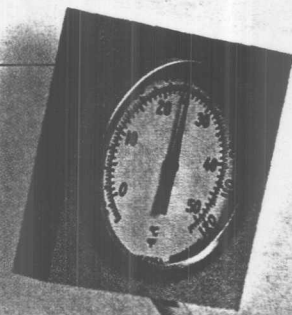


SENSORS SMARTEN UP

A NEW SMART-SENSOR STANDARD PROMISES TO BRING ORDER TO THE CHAOTIC WORLD OF SENSORS AND THEIR INTERFACES TO μ Cs AND NETWORKS. EMERGING 1451.2-COMPLIANT PRODUCTS EASE SYSTEM-DESIGN EFFORTS AND CUT COST AND SIZE.

CONNECTING SENSORS AND TRANSDUCERS to a network, for example, to one of the many fieldbuses, has traditionally entailed a major design effort. Sensor calibration and compensatory correction, timing issues, and the sensor/ μ C/network digital interface are some of the many factors you must address to achieve a successful design. The IEEE 1451.2 smart-sensor standard promises to topple the multistandard Tower of Babel by establishing standard transducer/ μ C/network protocols (Reference 1). Several recent

Photo courtesy Analog Devices

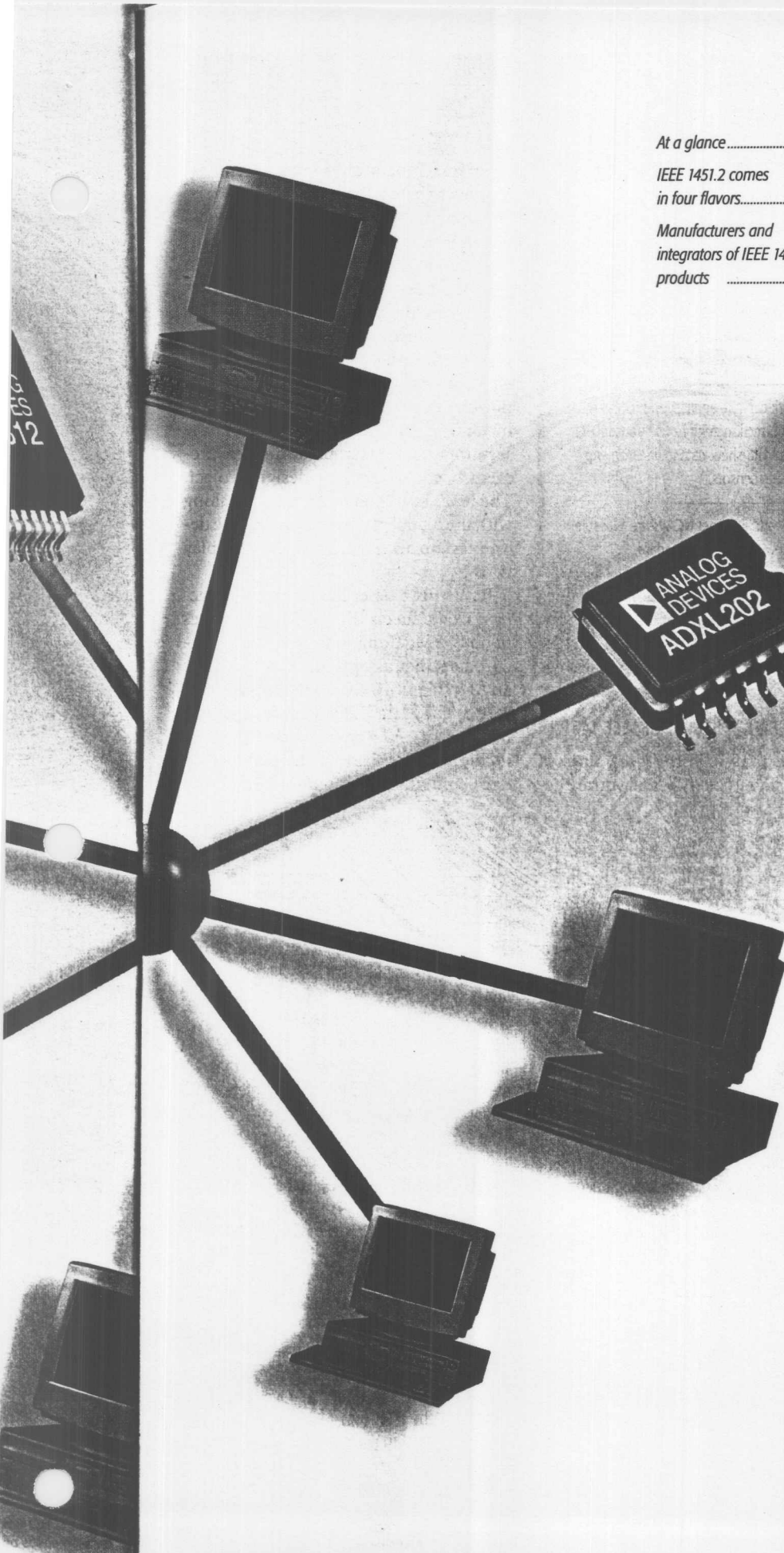


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products and development tools embody the IEEE 1451.2 protocols; you can expect to see an avalanche of products in the near future as the standard gains acceptance.

In simplest terms, IEEE 1451.2 specifies an "electronic data sheet" in a sensor module and also specifies a digital interface to access the data sheet, read sensor data, and set actuators (see sidebar "IEEE 1451.2 comes in four flavors"). The standard attempts to reduce the complexities designers have traditionally faced in establishing communications between various networks and transducers. These complexities include wiring, installation, calibration, error correction, and addressing network protocols. The goal of the IEEE 1451.2 standard is to provide an industry-standard interface to efficiently connect transducers to μ Cs and to connect μ Cs to networks (Reference 2).

The IEEE 1451.2 standard adds some new terms to your already brimming tureen of alphabet soup: *smart-transducer interface module* (STIM), *transducer-independent interface* (TII), *transducer electronic data sheet* (TEDS), and *network-capable application processor* (NCAP). Figure 1 shows a typical installation using the IEEE 1451.2 standard. Reference 3 gives details about the STIM, TII, TEDS, and NCAP. The STIM, for example, contains the TEDS, the control and status registers, interrupt masks, address and function-decoding logic, trigger, and trigger-acknowledge functions for the digital interface to the TII. The TII contains data-transport, clock, triggering, and acknowledge lines.



Operations that occur in the TII digital interface are: TEDS read, in which the μ C in the NCAPS reads the data in the STIM's electronic data sheet; sensor read, in which the NCAP accepts data from the sensor; TEDS write, in which the μ C writes data (for example, error-correction coefficients) to the TEDS; and actuator write, in which the NCAP sends data to an actuator. In the sensor-read operation, the NCAP triggers the STIM to begin sensor reading. Upon completion, the STIM issues a trigger-acknowledge signal, and the NCAP reads the sensor data. In the actuator-write operation, the NCAP writes values and triggers the STIM. The STIM performs actuation and issues a trigger-acknowledge signal.

IEEE 1451.2 handles several types of transducers: actuators and unbuffered, buffered, data-sequence, buffered-data-sequence, and event-sequence sensors. In a buffered sensor, the value returned to the NCAP is the value from the previous trigger to the STIM. A data-sequence sensor typically synchronizes its sampling time with the timing in the physical sys-

AT A GLANCE

► IEEE 1451 gives sensors Javalike network independence.

► Electronic data sheets in IEEE 1451.2 smart-transducer interface modules eliminate onerous manual calibration.

► Network-capable application-processor (NCAP) correction engines use transducer-electronic-data-sheet data to linearize and compensate sensors.

► RS-485 and Ethernet NCAPs are available for the new IEEE 1451.2 standard.

tem it is measuring. An event-sequence sensor is similar to a data-sequence sensor, but it does not return any data; the time of an event is the relevant information.

TEDS: THE HEART AND SOUL OF IEEE 1451.2

Imagine that it is the dark days of dumb-sensor technology, and you are de-

signing a temperature-measurement system for a factory-automation network. Perhaps you use a thermistor as the sensing element. You have to establish calibration tables for the sensors to be able to correct for nonlinearities. Maybe you enter the tables into EEPROMs or flash memory. Then comes the task of converting the analog sensor data using ADCs, taking into account the calibration-table error corrections. Add the timing and μ C-interface protocols, and the seemingly simple temperature measurement becomes a major design project. The IEEE 1451.2-mandated TEDS, along with the digital protocols, reduces the design task to an essentially plug-and-play effort.

Reference 4 describes the types of electronic data sheets IEEE 1451.2 mandates in an STIM, along with those the standard specifies as optional. Table 1 gives an overview of the various types of TEDS. The Meta TEDS contains the data that describes the entire STIM. The data includes the revision of the IEEE standard and the version number of the

IEEE 1451.2 COMES IN FOUR FLAVORS

IEEE 1451.2 is an IEEE-approved standard. This norm has three siblings in the works: P1451.1, P1451.3, and P1451.4. (The "P" indicates a proposed standard that is still in draft form.) The standards' titles are:

- P1451.1-Network-Capable Application Processor (NCAP) Model;
- 1451.2-Transducer-to-Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats;
- P1451.3-Digital Communication and TEDS Formats for Distributed Multidrop Systems; and
- P1451.4-Mixed-Mode Communication Protocols and TEDS Formats.

Reference A explains the relationship between the four interdependent standards. The goal of P1451.1 is to define the information model for networked smart transducers, as

well as the digital-interface specs for the model. Tremont Miao, product manager for sensors at Analog Devices, explains that P1451.1 is the key to imparting network independence to transducers. The goal of the P1451.1 working group is develop a "meta-language" that adapts NCAPs to various network standards and fieldbuses, much as Java and its "virtual machines" provide platform independence to software developers.

IEEE 1451.2 defines the mandatory TEDS in a smart-transducer interface module (STIM) and specifies the digital-interface and communications protocols between the STIM and the NCAP. P1451.3 arose because, in some harsh environments, it's not possible to physically attach the TEDS to the transducers. In other applications, the transducers may be distributed across an area in which it is undesirable to install

an NCAP for each transducer. In such systems, P1451.3 defines a standard digital interface for connecting multiple physically separated transducers in a multidrop configuration.

P1451.4 defines an interface for analog transducers that accommodate mixed-mode operation. The standard allows the analog transducers to communicate digital information for the purposes of self-identification and configuration. The transducer, with associated electronics, sends out manufacturer-generated TEDS data upon power-up or upon command. After sending this data, the transducer switches to analog mode and delivers analog sensor signals. The four IEEE standards work together to make the following scenarios possible:

- A 1451.2-compliant STIM connects to a P1451.1-compliant NCAP;
- A P1451.3-compliant trans-

ducer bus-interface module (TBIM) connects to a P1451.1-compliant NCAP that supports P1451.3-compliant interface and transducer blocks;

- A P1451.4-compliant mixed-mode sensor connects to a P1451.1-compliant NCAP that supports the P1451.4 interface;
- A P1451.4-compliant mixed-mode sensor connects to a P1451.1-compliant NCAP via a P1451.3-compliant TBIM;
- A P1451.3-compliant TBIM connects to a P1451.1-compliant NCAP through the 1451.2 interface via a conversion module.

REFERENCE

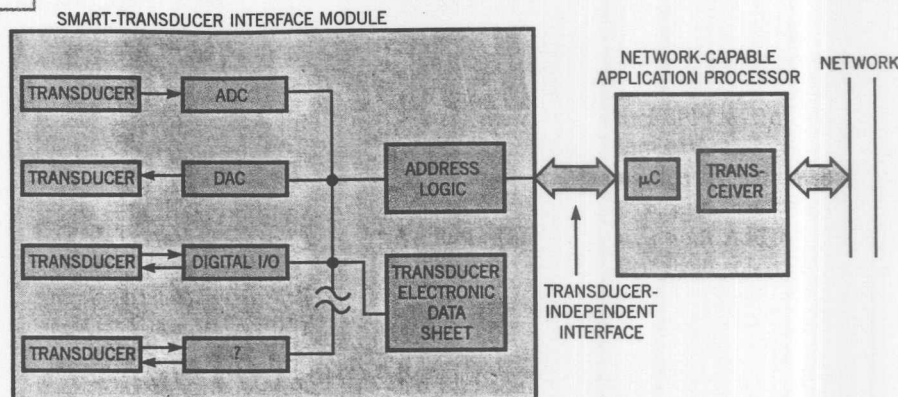
A. Lee, Kang, "An Overview of the IEEE 1451," Sensors Expo, May 19 to 21, 1998, San Jose, CA.

TEDS. It also contains the number of channels in the STIM and the worst-case timing parameters required to access the channels. The NCAP needs this channel information to access the channel data. The Meta TEDS also contains the channel groupings that describe the relationships between channels.

A Channel TEDS exists for each channel in the STIM. This electronic data sheet gives the details about each channel. The Meta TEDS lists the worst-case timing for the entire STIM; the Channel TEDS lists the timing parameters for the relevant channel. It also lists the type of transducer, the format of the data word at the channel's output, the physical units, upper and lower specification limits, accuracy figures, and whether the STIM has calibration information.

The Calibration TEDS contains the information to allow the NCAP to convert the raw output of the ADC in a STIM to the physical units called out in the Channel TEDS. For actuators, it contains the constants to allow the NCAP to convert the data in the physical units that the sys-

Figure 1



IEEE 1451 governs the electronic data sheet in the transducer module, as well as the digital interfaces between the module and the μ C and between the μ C and the network.

tem supplies to the format that the actuator requires. The Calibration TEDS also contains the last-calibration date and time and the calibration interval. For the calibration constants to be useful, an algorithm for using them must be available. The IEEE 1451.2 standard includes a general algorithm. If you need a differ-

ent algorithm, you must define a Calibration TEDS Extension to include in the Channel TEDS. The algorithm in the standard provides the capability for using other channels in the STIM to correct the output of a primary channel.

Referring to the "calibration table" for the dumb sensor discussed earlier, the

MANUFACTURERS AND INTEGRATORS OF IEEE 1451 PRODUCTS

For free information on devices such as the ones discussed in this article, circle the appropriate numbers on the postage-paid Information Retrieval Service card or use EDN's InfoAccess. When you contact any of the following manufacturers directly, please let them know you read about their products in EDN.

Analog Devices Inc

Norwood, MA
1-781-937-1428
fax 1-617-761-7607
www.analog.com
Circle No. 359

Bruel & Kjaer

Decatur, GA
1-800-332-2040
fax 1-770-987-8704
www.bkhome.com
Circle No. 360

Electronics Development Corp

Columbia, MD
1-410-312-6650
fax 1-410-312-6653
www.elecdev.com
Circle No. 361

Grayhill Inc

La Grange, IL
1-708-354-1040
fax 1-708-354-2820
www.grayhill.com
Circle No. 362

Hewlett-Packard Co

Everett, WA
1-425-335-2654
fax 1-425-335-2483
www.hp.com
Circle No. 363

Microsmith Inc

Scottsdale, AZ
1-602-443-4773
fax 1-602-443-4573
www.microsmith.com
Circle No. 364

The Modal Shop

Cincinnati, OH
1-513-351-9919
fax 1-513-458-2172
www.modalshop.com
Circle No. 365

Moore Products Co

Spring House, PA
1-215-646-7400
fax 1-215-646-3547
www.mpc.com
Circle No. 366

Object Automation

Santa Ana, CA
1-714-556-0500
fax 1-714-556-0520
www.oa.com
Circle No. 367

PCB Piezotronics

Depew, NY
1-888-684-0013
fax 1-716-685-3886
www.pcb.com
Circle No. 368

Seagull Technology Inc

Los Gatos, CA
1-408-358-7100
fax 1-408-358-7071
www.seagull.com
Circle No. 369

SUPER CIRCLE NUMBER

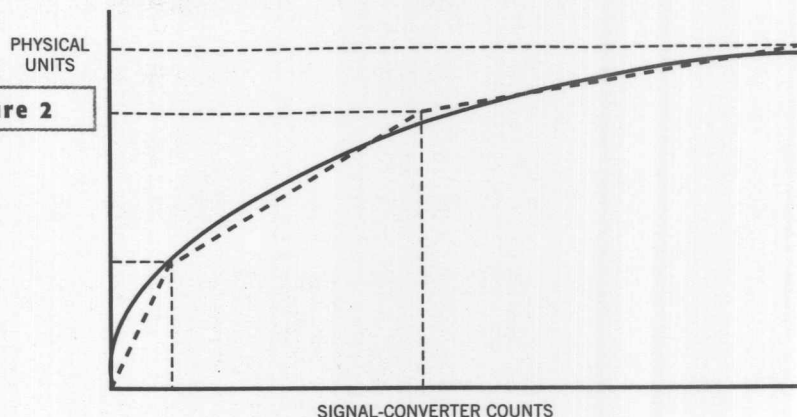
For more information on the products available from all of the vendors listed in this box, circle one number on the reader service card. Circle No. 370

Calibration TEDS stores an array of single-precision correction coefficients in a 2-D array, or table. This table, dubbed the "multinomial coefficient table," contains the correction factors for all the channels in the STIM. The NCAP uses these coefficients to perform calculations that correct the transfer function of the sensor or actuator in question. To avoid high-order polynomials, the standard uses a segmented calibration, in which each segment can have a variable width, offset, and number of coefficients (Figure 2, Reference 5). The NCAP should have a general correction engine that understands the calibration scheme, so it can run "blindly" no matter which transducer it works with.

The Generic Extension TEDS allows industry groups to provide additional TEDS that the IEEE working group does not anticipate in a machine-readable format. If a Generic Extension TEDS is present, the Channel TEDS identifies it. The Meta Identification TEDS is a human-readable memory space that the system may wish to retrieve from the STIM for display purposes. This TEDS contains fields for the manufacturer, the model number and serial number of the STIM, and a date code. It also includes the name of each channel grouping in the same order the groupings appear in the Meta TEDS.

A STIM can contain multiple channels that have some built-in relationship to each other. For example, one supplier might provide a three-axis accelerometer with the x axis as Channel 1, the y axis as

Figure 2



The compensation coefficients in the Calibration TEDS provide for a segmented transfer function, as deciphered in the NCAP.

TABLE 1—TYPES OF TRANSDUCER ELECTRONIC DATA SHEETS

Type	Readable by	IEEE 1451.2 mandate
Meta	Machine	Mandatory
Channel	Machine	Mandatory
Calibration	Machine	Optional
Generic-extension	Machine	Optional
Meta-identification	Human	Optional
Channel-identification	Human	Optional
Calibration-identification	Human	Optional
End-user application-specific	Human	Optional

Channel 2, and the z axis as Channel 3. Another supplier might use channels 7, 2, and 4 for the three axes. By creating a channel grouping and identifying which channel in the grouping represents each axis, the Meta TEDS allows the NCAP to correctly process the respective channels.

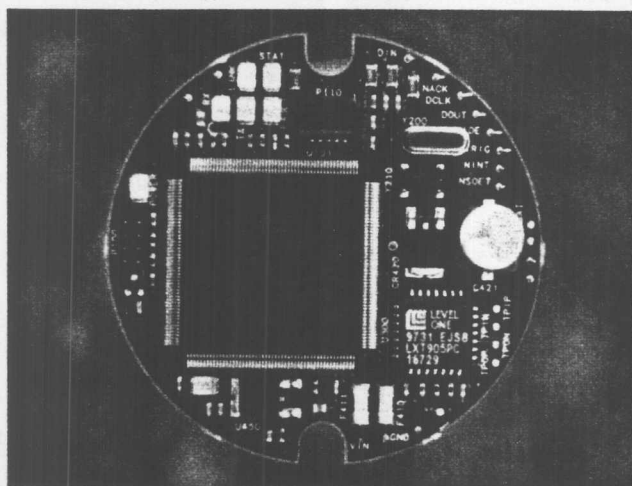
The Channel-Identification TEDS is similar to the Meta-Identification TEDS.

The Channel-Identification TEDS is useful when a STIM contains transducers from multiple manufacturers. This TEDS provides the same information for each channel that the Meta-Identification TEDS supplies for the STIM. It contains no channel groupings, because they exist only at the STIM level. The Calibration-Identification

TEDS provides a place in the STIM for details about the calibration. It can include such information as who performed the calibration and what standards the calibrator used. IEEE 1451.2 does not define the End-User Application-Specific TEDS; it provides a place to store information, such as the location and time of the installation, or any other details the user would like to save.

SMART PRODUCTS EMERGE

Product development for the IEEE 1451.2 standard is in its infancy. However, the emergence of IEEE 1451.2 as an approved standard has spurred a lot of design activity. Several companies have developed STIM-ready circuits, complete STIMs, and NCAPs. The AD μ C812 MicroConverter from Analog Devices is an example of a STIM-ready IC (Figure 3). The device contains a 12-bit ADC; two 8- or 10-bit DACs; an eight-channel multiplexer; and an on-chip μ C that holds 8 kbytes of program-flash EEPROM, 640 bytes of data-flash EEPROM, and 256 bytes of data RAM. According to Stan Woods, Hewlett-Packard project manag-



Hewlett-Packard's Bfoot-66501 Ethernet controller is an IEEE 1451.2 NCAP that you can customize using C or C++.

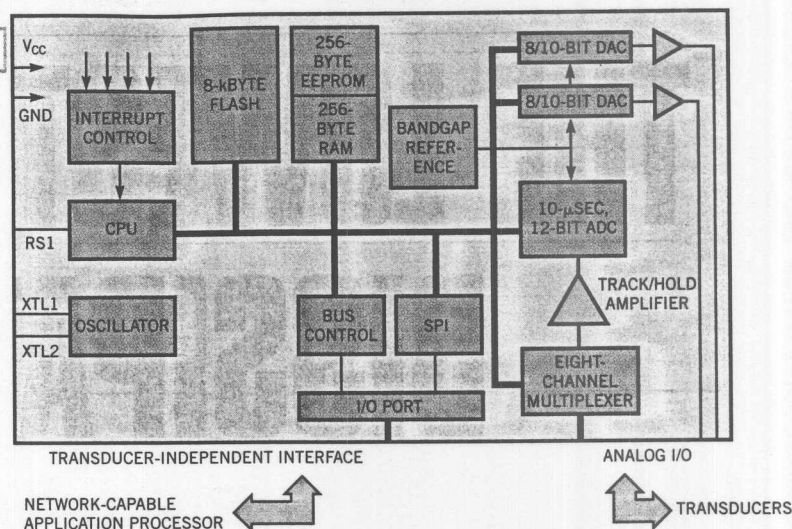
er and chairperson of the IEEE 1451.2 Working Group, the AD μ C812 contains all the elements you need to incorporate the IC into a STIM: the logic to implement the TII, memory to store the TEDS, and circuitry to convert sensor signals or drive actuators.

Although the MicroConverter is STIM-ready, the device is not restricted to use in IEEE 1451.2 systems. In fact, the data sheet for the new IC does not state specs in IEEE-1451.2 terms. To integrate the AD μ C812 into a smart-sensor system, you have to dig deeply into the IEEE standard to relate the standard's requirements to the IC's specs, memory allocation, timing characteristics, and logic capabilities. Analog Devices is preparing an application note, slated to appear soon, that provides "authoring tools" for writing IEEE 1451.2 TEDS in the MicroConverter's flash EEPROM. The application note, with associated software, will be available on Analog Devices' Web site.

The Analog Devices part and others like it are building blocks for developers that specialize in designing STIMs and NCAPs. Two such developers, deeply dedicated to the IEEE 1451.2 standards, are Electronics Development Corp (EDC) and Hewlett-Packard. Both companies use accelerometer and ADC chips from Analog Devices in their STIMs. EDC offers the Smart Transducer Interface Kit, a quick-start way to build STIMs. The 1451.2-KA kit contains two EDC 1451.2-SA interface modules. One interface module connects to an Analog Devices ADXL05 accelerometer; the second interface module allows you to connect your own transducers to build an IEEE 1451.2 STIM. The kit also includes software for calculating the channel-correction factors from calibration data and for generating, editing, and loading TEDS files into the STIMs.

The 1451.2-KA kit not only provides for STIMs, but also includes an RS-485 network node to provide the functions of an NCAP. The 1451.2-NA RS-485 Network Node includes an RS-232C serial interface and software that allows you to use a PC to load and view TEDS or to set and monitor transducers. Two RS-484 ports allow you to daisy-chain nodes. You can connect as many as 255

Figure 3



A complete data-acquisition system on a chip from Analog Devices contains the logic and memory needed to configure an IEEE 1451.2 TEDS, as well as the TII to the NCAP.

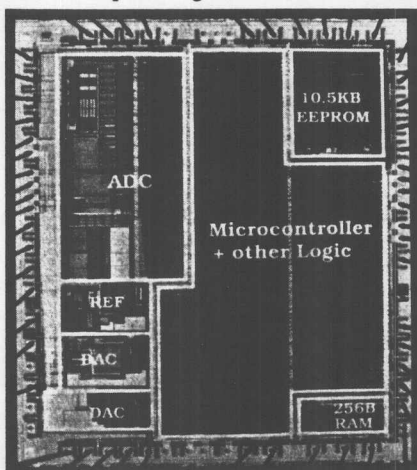
1451.2-NA nodes into a single RS-484 network. Each node contains its own electronic data sheet; each electronic data sheet contains the model number, the serial number, and a 32-bit identifier. The PC automatically finds each node and assigns it an 8-bit network identifier upon initialization of the network. This 8-bit identifier is present in all communications with the nodes.

A smart sensor from PCB Piezotronics complies with IEEE P1451.4. Models T356B07 and T356B08 vibration sensors identify themselves by model number, serial number, sensitivity, sensor type, and location when you address the devices. The sensors are compatible with IEEE-1451-compliant signal conditioners from

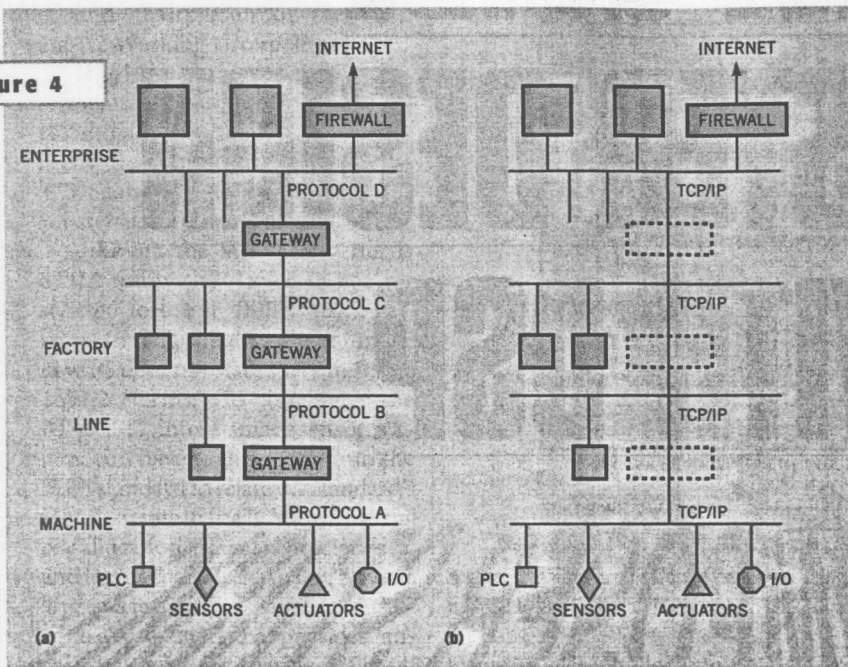
The Modal Shop. PCB offers a developer's kit for designers interested in incorporating a smart-sensor reader into their acquisition equipment.

IEEE 1451.2 promises to vastly simplify networking in systems using sensors and actuators. Ethernet makes the same promise. Ethernet is the penultimate open standard; it transports 10 Mbps. Hewlett-Packard recognizes the inherent potential in the marriage of the two open standards—IEEE 1451 and Ethernet—and is developing a series of compatible NCAPs. Figure 4 compares industrial networks using older, application-specific gateways (Figure 4a) and Ethernet-based, application-independent gateways (Figure 4b). In the non-Ethernet networks, you need an application-specific gateway every time field networks meet; in an Ethernet network, the routers, switches, and gateways control traffic.

The Bfoot-66501 embedded-Ethernet-controller board from Hewlett-Packard is a thin Web server for manufacturers of smart sensors and actuators. The module uses a custom ASIC to provide a complete plug-and-play Internet connection using standard interfaces. The Bfoot-66501 is a development board that accommodates round or rectangular form factors. You can customize the boards with HTML pages and Java applets. Client applications interface with HTTP, dynamic-link-library, Active X, and OPC protocols based on the IEEE 1451.1 common object model. The board is also an



The MicroConverter from Analog Devices contains all the logic and memory to comply with the TEDS and TII specs of IEEE 1451.2.

Figure 4

The use of Ethernet for a sensor/actuator network greatly reduces the need for gateways to make networks with different protocols communicate with each other and the system.

IEEE 1451.2 NCAP, for which you can create and download custom programs to a C or C++ programming environment supported by a library of function blocks from Hewlett-Packard.

The network interface for the Bfoot-66501 complies with 10BaseT Ethernet; the transducer interface satisfies IEEE 1451.2. The board uses a 68000-class μ P; it also contains a 500-kbit flash memory and more than 1 Mbit of RAM for user customization. Its IEEE 1451.2 interface driver includes a library of sensor and actuator device types and a full correction engine for STIM-based TEDS. Hewlett-Packard offers an option called Time

Sync. Time Sync uses standard Ethernet to synchronize the onboard clocks of all nodes to within 200 nsec. You can use this capability to make correlated measurements or to precisely control events. Time Sync increases your application's robustness by making measurement and control independent of network-traffic, application-logic, and μ P-stack jitter.

The products mentioned in this article are available now. However, many more products are in development, and many will probably become available by the time you read this article or shortly thereafter. Microsmith Inc, for example, is developing NCAPs for the LonWorks, SDS,

and DeviceNet network protocols. Microsmith constructs the devices of rugged aluminum, so you can mount them near transducers without additional enclosures. You can enter all parameters using a small keypad and monitor the NCAP's functions and settings with a two-by-eight-character LCD. Table 2 lists the IEEE 1451-related development efforts under way at several hardware and software companies.

The IEEE 1451 Working Groups are busy putting the finishing touches on the remaining draft specs. When finished, the ensemble will have a profound effect on the design of networked sensor and actuator systems. In the meantime, IEEE 1451.2 is an official standard, and you can proceed full steam ahead designing STIMs and the transducers that go into them. The National Institute of Standards and Technology (Gaithersburg, MD) is the governing body in the development of the IEEE 1451 standards. For information on the proposed and existing standards, you can contact Kang Lee at the NIST by phone at 1-301-975-6604, by fax at 1-301-990-3851, or by e-mail at kang.lee@nist.gov. To order the standards, contact the IEEE by phone at 1-800-678-4333 (1-732-981-0600 outside the United States and Canada) or by fax at 1-732-981-9667. □

You can reach Senior Technical Editor Bill Travis at 1-617-558-4471, fax 1-617-558-4470, b.travis@cahners.com.

**TABLE 2—COMPANIES DEVELOPING IEEE 1451-COMPLIANT PRODUCTS**

Company	IEEE 1451 projects
Analog Devices	STIM-ready accelerometers and ADCs
Boeing Commercial Airplane Group	IEEE 1451 interfaces for flight-test instrumentation systems
Grayhill Inc	Discrete sensors with IEEE 1451.2 interfaces
Hewlett-Packard	IEEE 1451-compatible Ethernet products
Microsmith Inc	IEEE 1451 NCAPs for various fieldbuses, such as DeviceNet, Ethernet, LonWorks, Profibus
The Modal Shop	IEEE 1451-compatible accelerometers
Moore Products Co	IEEE 1451.2-compatible pressure sensors and actuators
Object Automation	Man-machine interfaces based on IEEE 1451.1 from sensor input to enterprise level
PCB Piezotronics	IEEE 1451.4-compliant vibration-sensing instrumentation
Seagull Technology	IEEE 1451.1-compliant software modules and tools

REFERENCES

1. Travis, Bill, "Smart-sensor standard will ease networking woes," *EDN*, June 22, 1995, pg 49.
2. Miao, Tremont, "IEEE 1451.2, A Network-Independent Standard for Smart Transducers," presentation, Analog Devices Inc.
3. Johnson, Robert, and Stan Woods, "Overview and Status Update for IEEE 1451.2," Sensors Expo, Oct 5, 1998, Chicago IL.
4. Eccles, Lee, "A Brief Description of IEEE P1451.2," Sensors Expo, May 19 to 21, 1998, San Jose, CA.
5. Woods, Stan, "The IEEE 1451.2 Draft Standard for Smart Transducer Interface Modules," Sensors Expo, May 1997, Boston, MA.